THE EFFECTS OF TRANSPOSITION OF THE DAILY ROUTINE ON THE RHYTHM OF TEMPERATURE VARIATION.

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Although it has been known for many years that the rhythm of the daily variations in body temperature is remarkably constant, no explanation advanced is accepted as adequate and entirely satisfactory. When the enormous number of thermometric observations continually made in medical practice is considered, it seems strange that more attention has not been paid to the physiological aspects of variations in temperature. The immediate effects of bodily exertion and muscular work have only lately been adequately appreciated; and with reference to the influence of many other factors like sleep, alimentation, etc., much confusion still exists. Certain features of the daily rhythm are generally recognized, such as the rise of temperature during the forenoon and afternoon, and the fall during the evening and early morning hours. A study of the literature[1] indicates considerable differences in the incidence of the maximum and minimum temperature, depending undoubtedly upon a variety of causes. Despite differences as regards dietetic habits, work, age, etc., the time of maximum temperature may be limited broadly between 4 and 8 P.M., and that of the minimum between 2 A.M. and 7 A.M., with an average range of variation of over 1° C. in rectal observations. While a hot or cold climate may determine minimal variations in the peripheral temperature of the body, the internal temperature, as measured in the rectum, appears to suffer only very slight modifications from such causes. The rise in temperature incidental to muscular exertion is transitory. The following quotations serve to indicate prevalent views regarding the diurnal rhythm. Dr. Pembrey writes: "As regards the causes of the daily variation in temperature, muscular activity and food appear to be the most important factors. In ordinary life man is most active and takes food during the day, and is least active during the night. . . . We may conclude that the daily variation in temperature is one of the features of a corresponding variation in the activity of the tissues of the body, as shown by the rate of the contraction of the heart, the frequency of respiration, the intake of oxygen, the output of carbon dioxide, the discharge of urea, and the capacity for muscular work."[2]

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[1] An admirable review of the literature on this subject will be found in Pembrey's article in Schäfer's Text-book of Physiology, 1898, vol. i. p. 798, and in Richet's Dictionnaire de Physiologie article Chaleur, p. 91.

[2] Schäfer's Text-book of Physiology, 1898, vol. i. p. 801 *et seq.*

According to Prof. Richet, the daily variation of about 1° C. is "explicable en partie seulement par l'activité psychique et l'activité musculaire, et due surtout aux variations de tonicité du systeme nerveux régulateur de la chaleur." Jürgensen's observations on fasting subjects in which a more or less "normal" curve of temperature variations was maintained exclude the diet factor from a preponderating role. In estimating the relative importance of the bodily activities as distinguished from other environmental conditions, studies on the influence of the inversion of the daily routine have been made. The most recent are those of Benedict;[1] they claim special interest, because the observations were practically continuous over long periods of time. Such an arrangement was made possible by the use of a specially devised electric resistance thermometer reading to 0.01° C., which can be inserted 10 cm. to 15 cm. in the rectum and retained there without inconvenience during both waking and sleeping hours. Two subjects were carefully observed by Benedict: one a person usually working during the day, but made to work at night and sleep during the day for a series of consecutive days; the other, an individual long accustomed to night-work in the capacity of a night watchman. With reference to the first subject, Benedict concludes: "It is obvious that, at least with this subject, the influence of the inversion of the daily routine on the body temperture curve is noticeable only during the day, for while the evening fall, the early morning minimum, and the morning rise persist, the period of sleep during the day causes a marked fall of temperature, followed by a rise on awakening.

"The effect of the consecutive nights of night-work has not, therefore, succeeded in producing any marked disturbances of the curve between 6 P.M. and 8 A.M. By repeating the experiment and obtaining a curve after twelve consecutive nights of night-work, no greater tendency to influence the normal course of the curve, even after the somewhat longer period of work by night, is apparent.

"While the data of these two curves may warrant our regarding the temperature curve between 7 P.M. and 8 A.M. in a general way as fixed and independent of sleep or work (exempting severe muscular work), the curve during the remainder of the twenty-four hours—*i. e.*, 8 A.M. to 7 P.M.—undergoes marked alteration when sleep is taken in this period." Since this experiment indicated that the general form of the night curve is so firmly fixed as not to be materially altered, even after an inversion of the daily routine for ten or twelve days, the second experiment was conducted on a subject accustomed to a complete inversion of the daily routine for years. Prof. Benedict writes of this series of observations: "The remarkable course of these curves certainly cannot readily be explained as the result of influences ordinarily considered as affecting body temperature. Obviously, we have here to do with some influences other than the ingestion of food, muscular activity, sleep, and body position. Of the main characteristics of the normal curve, the evening fall, the early morning minimum, and the morning rise are unmistakably found in both of these curves. The evening fall, though considerably diminished in amplitude, is sufficiently well marked to be easily recognized, and the early morning minimum and morning rise are likewise clearly seen. . . . It is thus seen that while years of night-work have not succeeded in eliminating the tendency to an evening fall, a minimum sometime during the night, and the morning rise, the whole course of the curve is markedly different from any with which we are familiar, and any study of the factors influencing the course of the curve must include a large number of experiments, in which the habits of life, times of eating, and muscular activity should all be as nearly alike as possible, in order to compare the results with the normal curves given by the several writers on body temperature."

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[1] Studies in Body Temperature, American Journal of Physiology, 1904, vol. xi. p. 145.

From the preceding observations it has been assumed that the general form of the night curve remains practically intact, even when the daily routine is inverted, indicating a fixity of rhythm that is difficult to explain. As Benedict says: "Why the temperature of the human body reaches a minimum at 2 A.M. to 6 A.M., independent of whether the subject is sleeping soundly in the recumbent position or whether he is awake and sitting, or even standing and walking, is a problem that calls for extended research."

In view of the failure to note any marked inversion of the temperature curve by inverting the routine of life, it may be asked whether cosmic rather than bodily influences are the determining factors. Or, is the temperature rhythm a physiological function early established in the individual and largely independent of external impressions? Some light upon the question might be thrown by observing the changes of temperature rhythm which may attend the gain or loss of time incidental to a journey around the world. An opportunity to make a few notes on the subject was afforded the writer by a recent trip to the Philippine Islands. Manila time is approximately eleven hours earlier than that of New Haven. Accordingly, a journey from New Haven to Manila involves the shifting of the daily routine, so that day and night are practically reversed. What happens to the temperature curve?

The majority of the observations to be reported were made by the writer upon himself. Several persons in Manila (including one who made the same trip) permitted the collection of a few additional notes, which, however, I have not discussed in detail. Dr. Richard P. Strong, of the Insular Laboratory, has confirmed, in part, my own work by recording the temperatures of himself and of a second person and from observations on his patients. Major Bannister, in command of the First Reserve Hospital at Manila, has also furnished me with some records obtained by a number of hospital-corps men on themselves.

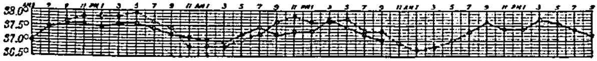
All observations were made with the ordinary clinical one-minute thermometers. The limitations of the methods commonly employed are too well known to require discussion here. Rectal temperatures could be taken with convenience only in the writer's case. Temperature readings were made every two hours. Records made on the writer were kept for the whole day, as well as for both longer and shorter intervals; in the other experiments observations were continued for a part of the twenty-four hours only, but sufficient material can be obtained in this way to ascertain the characters of the curves. The readings by the hospital-corps men were, perhaps, not made with the care which is desirable in scientific work; however, trustworthy subjects were chosen and the records made on a large scale. The precautions taken to make the results on the writer comparative included usually the maintenance of the same bodily activity for an appropriate period before each temperature observation (except when sleeping). The thermometer was inserted 7 cm. to 8 cm. into the rectum for at least five minutes before each reading. Care was also taken to follow the same regular habits of life previously practised in New Haven.

TRANSPOSITION EXPERIMENTS ON R. B. G.

Itinerary of the Trip. The start from New Haven was made on June 24th and the arrival at Manila occurred August 1st; the time required for the trip over was, therefore, thirty-seven days. The return from Manila began September 15th; Nagasaki to the north was left a week later, and the journey ended at New Haven on November 1st, forty-eight days after sailing from the Philippines. Short stops of a day or two at Chicago, San Francisco, Honolulu, and Guam delayed somewhat the trip westward; and a few days at Nagasaki, San Francisco, St. Louis, and Chicago also prolonged the time of travel for the return to New Haven.

Control experiments for a period of two days, June 21st, 7 A.M., to June 23d, 7 A.M., were made just before leaving New Haven. The resulting curves (Chart I.) are practically normal in character.

CHART I.



The broken line in this and the following charts is the record of the control, New Haven observations; the other, the Manila observations of August 5th, 6th and 7th.

There is a tendency for the temperature to be somewhat high in the morning, but this is not an unusual observation. The maximum at 5 o'clock in the afternoon, the evening fall, the early morning minimum (1 A.M. to 3 A.M.) and subsequent rise, and the range of variation are typical. The summary of the observations follows:

	Maximum.	Minimum.	Temp. range.	Mean.
June 21-22 (24 hours)	37.9°+ (5 P.M.)	36.8° (1 and 3 A.M.)	1.1°	37.4°
June 22-23 (24 hours)	[1]37.8 — (11 A.M.) 37.7 — (5 P.M.)	36.7 (1 A.M.)	1.1 —	37.3

Observations at Manila were made in three periods, with intervals of about three weeks:

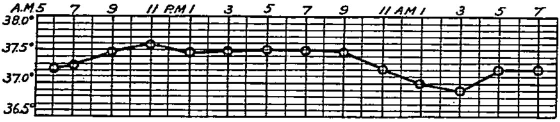
1. The first series (Temperature Chart I.) was begun four days after landing. The observations for this period afford a typical "normal" curve. The maximum is somewhat earlier in the afternoon than in the New Haven controls. The temperature range is little over half that in New Haven. There is a slight morning fall:

	Maximum.	Minimum.	Range.	Mean.
August 5-6 (5 A.M.-7 A.M. 26 hours)	37.6°—(3 and 5 P.M.)	37.0° (1 and 3 A.M.)	0.6°	37.3°
August 6 (7 A.M.-9 P.M.)	37.7— (5 P.M.)	....	......	......
August 7 (5 A.M.-9 P.M.)	37.7— (3 P.M.)	....	......	......

2. These results (Chart II.) for August 22d and 23d are of the same character as the preceding series:

	Maximum.	Minimum.	Range.	Mean.
August 21 (9 A.M.-5 P.M.)	37.7° (3 P.M.)	....	......	......
Aug. 22-23 (6 A.M.-7 A.M. 25 hours)	37.6 (11 A.M.) 37.5 (5 and 7 P.M.)	36.9° (3 A.M.)	0.6°	37.3°

CHART II.

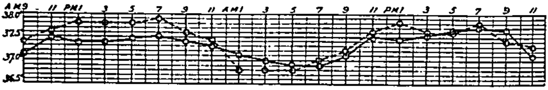


Observations at Manila, August 22d and 23d.

3. The third set of observations (Chart III.) for September 9th and 10th show no noteworthy differences from the two series previously recorded:

	Maximum.	Minimum.	Range.	Mean.
Sept. 9-10 (7 A.M.-7 A.M. 24 hours)	37.5° (9 A.M. and 5 P.M.)	36.9° (3 and 5 P.M.)	0.6°	37.3°—
Sept. 10 (7 A.M.-9 P.M.)	37.7° (5 P.M.)	....	......	......

CHART III.



Manila, September 9th and 10th.

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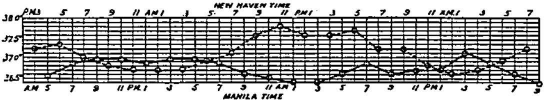
[1] This high figure is associated possibly with some slight bodily exertion prior to recording the temperature.

It is seen from the charts of the observations given above that the general form of the Manila curve corresponds in outline closely to the course of a typical temperature record. The morning rise, the late afternoon maximum, the characteristic evening fall, and the early morning minimum—all these important variations are found to occur much as usual. Even before the writer was accustomed to retire (shortly after 11 P.M.), the evening drop was well down toward the minimal figure for the twenty-four hours. A comparison of the Manila and the New Haven control curves brings out in a very forcible manner the analogy of the one set with the other. Some features of the above observations deserve, however, to be examined more fully in detail.

A slight, though noticeable, lowering of the temperature in the morning is a somewhat persistent character throughout the three series. However, variations of the same nature are not uncommonly met with in normal observations (see, for example, the controls and the later New Haven records). In fact, a rapid morning rise succeeded by a slight fall is so prominent a feature in the results of former temperature investigations that it has led in the past to some uncertainty regarding the actual time of the daily maximum.[1] It is improbable, therefore, that the slight fall is produced by the continued existence of the coincident evening temperature depression found in the earlier New Haven curve. In the inversion experiments of both U. Mosso[2] and Benedict, the evening fall persists to a very much more striking degree, and follows fairly closely the line of the normal control curve.

The daily temperature range (0.6° +) is unusually limited; it is somewhat over half that observed in New Haven. The difference between the New Haven and the Manila maxima (about 0.2°) is practically the same as that of the respective minima, so that a medial abscissa to a set of the Philippine extremes occupies the same relative position to the limits of the New Haven variations. If the Manila curves and the controls are plotted together (Chart IV.), so that the succession of simultaneous events in the two places is comparable, it will be seen that the two sets of observations are practically exactly reversed. It might be argued, accordingly, that the

CHART IV.



New Haven controls and Manila records of August 5th and 6th; plotted eleven hours apart.

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[1] Pembrey. Schäfer's Text-book, vol. i. p. 798.

[2] Arch. ital. d. biologie, 1887, vol. viii. p. 177.

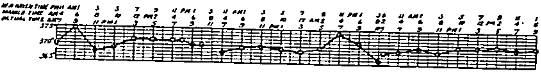
small range may be due to an antagonistic influence exerted by the persistence, to some degree, of the original New Haven characters. Later observations during the return trip (*vide infra*) indicate, however, that this cannot be the case. The explanation of the limited variation must be sought probably in the changed environment; it is to be found presumably in the new climatic conditions and the quieter life of the tropics.

In the five and a half weeks from the first to the third series of observations, the character of the curves underwent no noteworthy alterations. The mean temperature for the day remained practically uninfluenced by the transposition.

Observations during the return journey were made to ascertain if the daily change of twenty minutes or so in time had any immediate effect on the typical rhythmic variations. The return curves were found to be apparently independent of the possible persistence either of the Manila or the New Haven characters. The temperature variations seem to be adjusted to the gradual transposition of routine forced upon the body by the nature of the trip:

1. The first of the two series was made on October 1st, 2d, and 3d, between longitude 165° east and 180°; the actual time was, therefore, eight and one-third to seven and two-thirds hours earlier than that of New Haven, and three to three and two-thirds hours later than at Manila. The curves are given in Chart V.

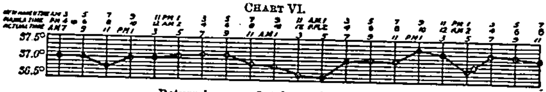
CHART V.



Return journey, October 1st, 2d, and 3d.

2. Observations were made October 14th and 15th between longitude 134° west to 129° west (Chart VI.); the time was four and one-third to four hours earlier than at New Haven. A summary of the twenty-four hours, beginning October 14th, at 7 A.M., follows:

CHART VI.



Return Journey, October 14th and 15th.

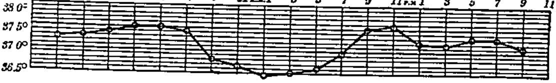
Maximum.	Minimum.	Range.	Mean.
37.1° (7 and 9 P.M.)	36.3° (5 A.M.)	0.5°	36.9°

The temperature variations in both series show a tendency to be unusually limited—a condition of affairs probably associated with the sedentary character of the life as a passenger on a transpacific steamer for some length of time. Some abrupt and apparently unexpected variations are found in the first set, but these are capable of explanation. Thus, the sudden elevation on the morning of October 1st (Chart V.) is possibly associated with a rather vigorous walk on deck, followed by an unusually hearty breakfast, though the writer had been quiet for at least an hour before the observation at 9 A.M. The high figure at 7 P.M. on October 2d may also have been influenced by activity some little time previous to taking the temperature; the functional processes were probably aroused through unusual exertion from a lethargy induced by the character of the life aboard ship. To prevent possible variations of this sort was one object of the experiment on October 3d, in which a uniform (and quiet) state of bodily activity was maintained so far as practical during the day. The record shows an unusually small temperature change, though otherwise the curve presents the "normal" characters.

If the above explanation of these variations can be accepted, the records of October 1st and 2d are fairly regular. At least they fail to show any persistency either of the Manila or the original New Haven influences.

The later observations on the 14th have the time of the maximum and minimum points occurring about two hours later than might be expected from a consideration of the character of the previous observations. In fact, the first half of the curves of this series follows closely the actual time relations of the New Haven controls. The small temperature range (0.5°) for the first twenty-four hours cannot here be due to any antagonistic influences of the original rhythm. The rest of the record on October 15th would probably have been of the ordinary type throughout if the writer had not inadvertently fallen asleep between 3 and 5 o'clock in the afternoon. The fall in the curve for this period is coincident with the condition of physical and mental depression.

CHART VII.

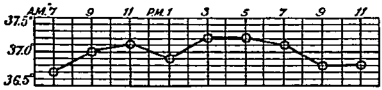


November 3d and 4th at New Haven.

Observations on arrival at New Haven were recorded on November 3d, 4th, and 6th. The curves (except November 4th) are normal in character and resemble the earlier New Haven observations closely. The thermo-regulatory mechanism has been readjusted to the former conditions. The mean temperature, however, is low. The curves are plotted in Charts VII. and VIII.

	Maximum.	Minimum.	Range.	Mean.
Nov. 3-4 (7 A.M.-7 A.M.)	37.5° (3 and 5 P.M.)	36.4+° (1 A.M.)	1.1°—	37.0°
Nov. 4 (7 A.M.-9 P.M.)	37.5 + (11 A.M.) 37.3 (5 and 7 P.M.)	....	......	......
Nov. 6 (7 A.M.-11 P.M.)	37.2 (3 and 5 P.M.)	....	......	......

CHART VIII.



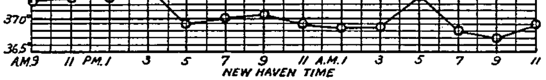
November 6th at New Haven.

Inversion of the Manila routine should give a result practically of the same character as the New Haven observations if the original rhythm can still persist uninfluenced by the transposition. Difficulties made such an experiment unpractical in Manila, but the attempt was made on shipboard between that city and Nagasaki, which lies almost to the north of the islands.

The experiment was so arranged that the routine should correspond almost exactly with the New Haven program. Only a few hours' sleep were taken on the night of September 17th and 18th, and the latter part of the morning and the afternoon were spent in slumber. Temperature observations were begun at 10 P.M. on this day. Sleep on the 19th was fairly good, but the writer became very tired at night, notwithstanding the six or seven hours' rest. As comparable bodily conditions were not being maintained, the experiment was interrupted, and, unfortunately, could not be repeated. The curve is plotted in Chart IX., and the summary for the day follows:

Maximum.	Minimum.	Range.	Mean.
37.5° (4 A.M.) (N. H. time = 3 P.M.)	36.7° (10 P.M.) (N. H. time = 9 A.M.)	0.8°	37.0°

CHART IX.



Inversion experiment.

The curve resulting from the inversion is somewhat difficult of interpretation. The characteristic night depression apparently had not occurred to any extent when temperature observations were begun. The maximum figure coincides fairly well with the time for the occurrence of the corresponding New Haven variation. Though not quite typical, the rapid depression in the morning (3 P.M. to

5 P.M., New Haven time) is somewhat suggestive of the early evening fall in the original curve; certainly, it is not characteristic of the Philippine records. The later observations seem to be referable rather to a readjustment of the Manila conditions, modified somewhat by the unusual state of the bodily activities during the late morning and afternoon. After a refreshing sleep, the temperature rises suddenly to a figure which corresponds with the ordinary Manila reading at this hour, but which is also coincident with the New Haven morning elevation. The usual evening fall then manifests itself. The subsequent slight rise at midnight is the result probably of an attempt to throw off the physical and mental depression occurring notwithstanding the sleep obtained during the day. On the whole, the experiment does not exclude but rather suggests the possibility of a return of the temperature rhythm in part to the New Haven character if comparable conditions of inversion are maintained.

OBSERVATIONS ON OTHER SUBJECTS.

In a series of observations on other individuals all the precautions desirable to avoid the occurrence of preventable error could not be taken. Comparable conditions of the body as to sleep, time of eating, exercise, etc., were frequently not obtainable. The readings were occasionally made at irregular intervals, and are over shorter periods than the writer employed in his own case.

The temperature record of the other subject who made the trip from New Haven to Manila comprises controls for a period of two days and two sets of observations in the Philippines. The New Haven variations (axillary temperatures) were perfectly normal in character. The Manila experiments (both axillary and sublingual readings), like the results on the writer, show an apparent adjustment of the temperature variation to the new conditions. Though a month apart in point of time, no essential differences were noted between the series made shortly after landing and the later set of observations.

Additional collected data corroborate the facts already presented. Thus, curves were obtained of the daily temperature variations in two individuals who have resided in the islands for two and a half years and who originally went over from this country. The results here indicate a permanent adjustment to correspond with the transposition of routine.

Temperature observations were also made by Dr. Strong, of the Insular Biological Laboratories, on himself and others who had resided for various lengths of time in Manila. The rise during the morning and early afternoon was found to occur as usual and was normal in character. No trace of the persistence at Manila of the original evening fall was apparent in Dr. Strong's experiments. Finally, the temperature records of eight hospital-corps men (on both day and night details) give no evidence that transposition of routine affects the daily rhythmic variations in a manner other than has been already described.

The daily rhythmic temperature variation has been shown to be shifted in point of time. It is, therefore, capable of being shifted at least gradually. Why, then, does not inversion of the routine produce a corresponding alteration in the temperature curves obtained under these conditions? In the course of the present investigation the existence of some relationship between the functional "tone" of the body and the variations in the temperature record has repeatedly been impressed upon the writer. For instance, whether beginning at 7 P.M. or at 11 P.M., the first portion of the evening temperature fall seems to be coincident with the onset of a state of physical and mental depression. It is possible that the explanation of Benedict's results is to be found in the depressing effects of environmental conditions, such as darkness, artificial illumination, the unusual absence of noise and external activity, and in the habitual and regular reactions of the body to these influences.

SUMMARY. The transposition of the daily routine through a period of practically half a day, experienced as the result of the time changes during the trip from New Haven to Manila, was accompanied by an immediate adjustment of the rhythmic temperature variation to the new régime in the case of the writer and of a second subject, so that on arrival in the islands the curves obtained were still "normal" in character.[1] Subsequent residence in the Philippines for a period of about six weeks induced no alterations of any significance. Observations (on the writer alone) made during the return trip showed an apparent adjustment of the temperature rhythm day by day coincident with the shifting of the routine. After returning to New Haven the record continued to be normal and resembled closely the earlier controls. Inversion of the Manila program seems to prevent the usual evening fall and early morning minimum, if comparable bodily conditions are maintained; the single experiment on the writer, however, is an inadequate basis for a positive statement. Additional observations on individuals who came originally from the United States, and who have resided in Manila for varying periods of time, corroborate in part the results on the writer, in so far as the temperature rhythm was found to be of the ordinary type. No evidence has been obtained that any of the Manila temperature variations are associated with the persistence of the original normal features, a result contrary to the facts brought out by Benedict's experiments on routine inversion. Transposition of the daily routine, therefore, appears to produce a corresponding and coincident shifting of the rhythmic temperature changes, so that the normal character of the variations is always preserved.

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[1] Except for a somewhat limited daily range of variation.

It is to be hoped that one result of the publication of the present paper will be to draw attention to a subject of considerable physiological interest and importance. The observations need to be corroborated and extended. Additional data should be furnished concerning the effects of transposition and inversion of the daily routine, not only on temperature, but on other rhythmic functional variations as well.

I desire to express my indebtedness to Prof. Mendel, of this laboratory, for suggestions offered, and to Dr. Strong, of the Insular Biological Laboratories, and Major Bannister, of the United States Army, for their interest and helpful co-operation.

A STUDY OF THE METABOLISM OF A VEGETARIAN.

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The patient, a student in one of the departments of the University of Pennsylvania, on whom the observations here reported were made, consulted me on March 10, 1903, complaining of a mild infection of the respiratory tract. He was then twenty years old, tall, anæmic-looking, and not at all robust in make-up. During the course of my examination I determined that the infection was not of a tuberculous nature, and learned that the patient was the son of vegetarian father and mother, and that his grandparents had also been vegetarians, as he was himself. I induced him to weigh and record the articles of his diet, to furnish me with his entire twenty-four hours' urine, and to keep a record of his body weight daily for a week. He also submitted samples of the milk that he drank, so that I might determine the amount of nitrogen that he was ingesting with this article of diet, the only animal food that he took.

From the submitted twenty-four hours' urine I determined (1) the total volume passed, (2) the amount of nitrogen excreted, with its equivalent in urea, using the Kjeldahl method, and (3) the phosphorus excretion expressed as P_2O_5, using the uranium acetate method.

From the diet lists submitted I calculated the amount of nitrogen ingested with the food as follows: The Kjeldahl method was used on five specimens of milk, thus giving an accurate estimate of the amount of nitrogen ingested with that food. From these five determinations an average was taken, and the nitrogen in the remainder of the milk used, samples of which, for one reason or another, could not be obtained, was estimated, using that average as a basis. The